The Geometry-dependent Lambertian-equivalent surface reflectivity (GLER) product for cloud and trace-gas retrievals

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Background

Reflection of incident sunlight by the Earth's surface is generally anisotropic. The dependence of surface reflection on illumination and observation directions is described by the bidirectional reflectance distribution function (BRDF). Surface BRDF information is required for most satellite retrievals of atmospheric composition. For those algorithms that use Lambertian-equivalent reflectivity (LER) climatologies (which do not account for BRDF effect), such as most cloud and trace gas retrieval algorithms in the ultraviolet-visible (UV-Vis) region, we introduced the concept of Geometry-dependent LER (GLER) to capture solar and satellite viewing angle dependence as well as daily and seasonal changes due to the change of surface (Vasilkov et al., 2017; Qin et al., 2019 and Fasnacht et al., 2019).

- GLER is calculated by coupling the atmosphere with anisotropic surface models such as the MODIS surface BRDF model and BRDF/Albedo product for land, and a model of reflection and water-leaving radiance for water. The GLER data adequately account for surface BRDF effects while simplifying the surface BRDF implementation in the existing satellite retrieval algorithms.
- We have produced global GLER products for the whole suite of sensors considered in our new multi-satellite nitrogen dioxide (NO2) data product (MINDS, see Lamsal et al., 2021), developed under NASA's Making Earth Science Data Records for Use in Research Environments (MEaSUREs) program. These sensors include OMI (Ozone Monitoring Instrument onboard the Aura satellite), TROPOMI (Tropospheric Monitoring Instrument onboard the Sentinel-5 Precursor satellite), GOME (Global Ozone Monitoring Experiment on ESR-2), and GOME-2 (on MetOP A/B/C platform). GLER approach will also be applied to NASA's TEMPO (Tropospheric Emissions: Monitoring of Pollution) instrument, a future UV-visible spectrometer.

Methodology

GLER is derived from the following equation:

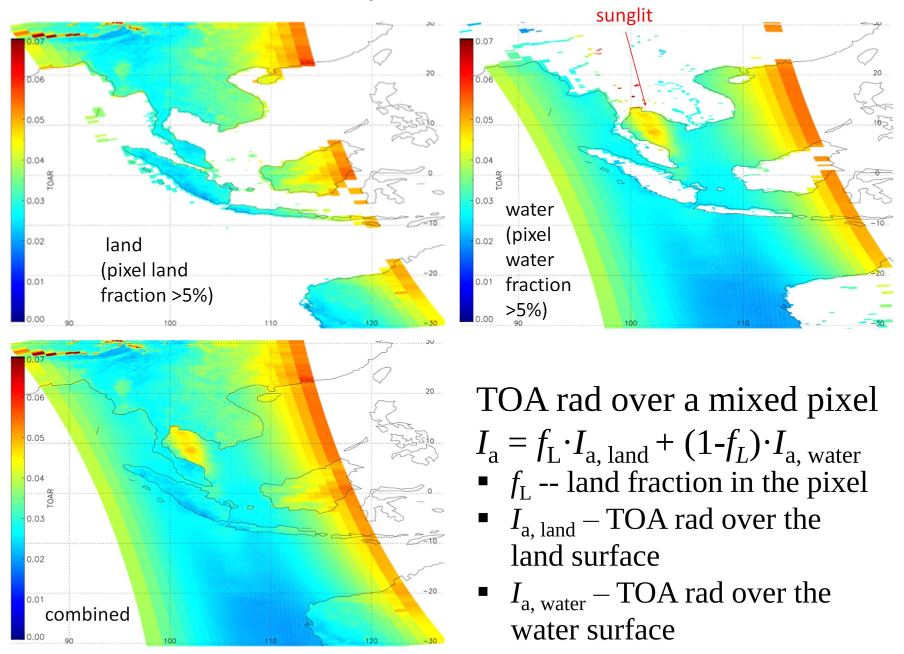
$$I_{TOA} = I_0 + \mathrm{GLER}*T/(1 - \mathrm{GLER}*S_b)$$

VLIDORT (vector linearized discrete ordinate radiative transfer model) is used to calculate the top of the atmosphere radiance (I_{TOA}) for a Rayleigh atmosphere over a non-Lambertian surface. I_0 is the path scattering radiance by the atmosphere. T is the transmitted radiance. S_b is the diffuse flux reflectivity of the atmosphere.

- Over land, the MODIS-derived Ross-Thick Li-Sparse (RTLS) BRDF function and BRDF product (MCD43GF or MCD43C1, see Table 1 for detail) is applied and averaged over sensor's field of view (FoV).
- Over ocean, models to accounts for both light specularly reflected from the rough ocean surface (Cox-Munk slope distribution depending on wind speed as specified in Table 1) and diffuse light backscattered by water bulk (i.e., contribution from water-leaving radiance with Chlorophyll concentration specified in Table 1 as the only input).
- Look-up tables for I_0, T and S_b are generated also with VLIDORT.

Combining land and water TOA radiances to derive GLER

TOA radiances over land, water and the combined



TOA rad over a mixed pixel

$I_a = f_L \cdot I_{a,\,land} + (1-f_L) \cdot I_{a,\,water}$

- f_L -- land fraction in the pixel
- $I_{a,\,land}$ – TOA rad over the land surface
- $I_{a,\,water}$ – TOA rad over the water surface

Examples of pixel-based GLER

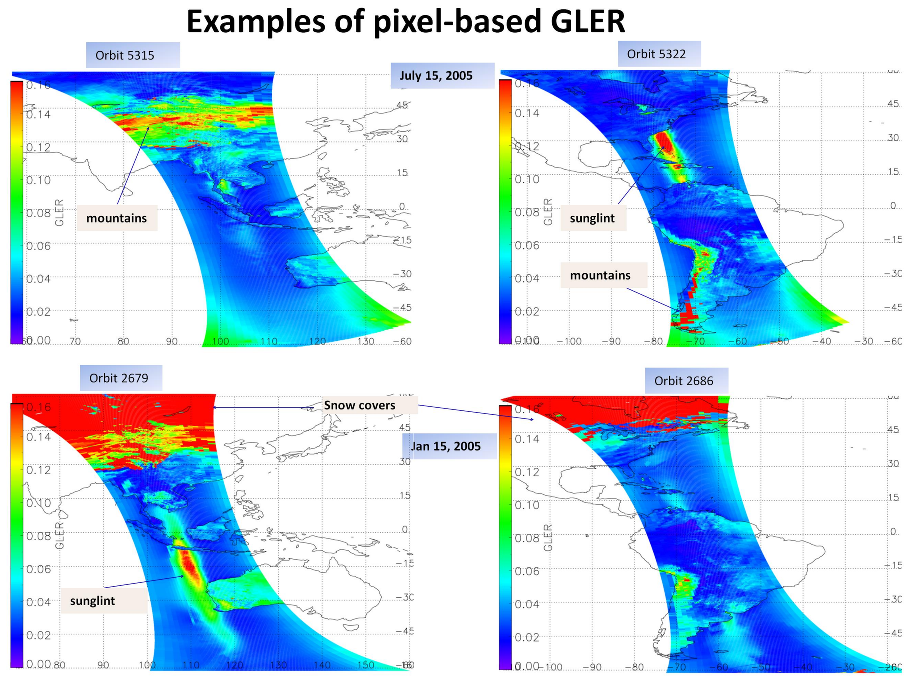
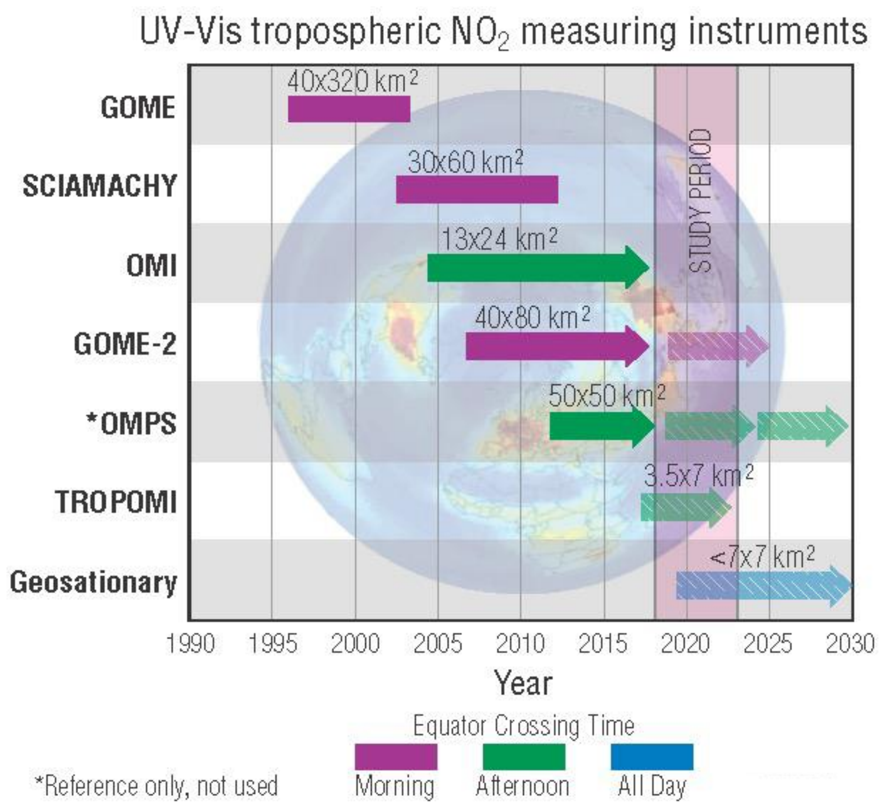


Table 1. Spatial and temporal resolutions of major ancillary data

Parameter	Source	Spatial	Temporal
Land-water flag	MODIS	30 arcsec	fixed
Land BRDF coefficients	MCD43GF or MCD43C1 from MODIS	30 arcsec or 2.5 arcmin	8-days or daily
Wind speed	SSMIS/F16	0.25 deg	daily
Chlorophyll	MODIS/Aqua	2.5 arcmin	monthly
Snow/ice	IMS[1] (NH) or NISE[2] (SH)	4 km or 25 km	daily
Terrain pressure	GMI/GMAO	0.25 deg	hourly

[1]IMS is from the U.S. National Ice Center; [2]NISE is from NOAA National Snow and Ice Data Center. We do gap-filling of MCD43C1 data using the daily BRDF climatology created from V006 MCD43GF record.

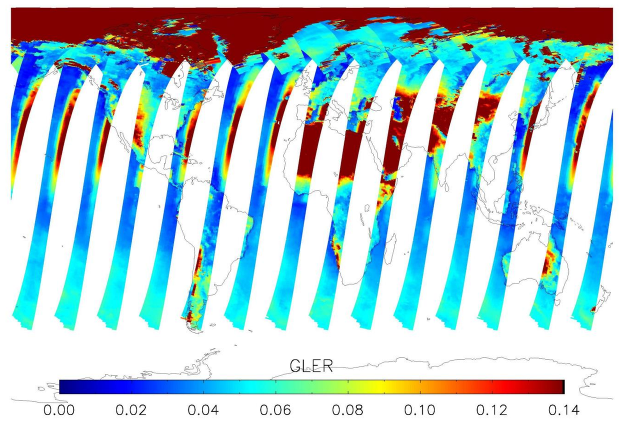
GLER products for sensors considered in MINDS

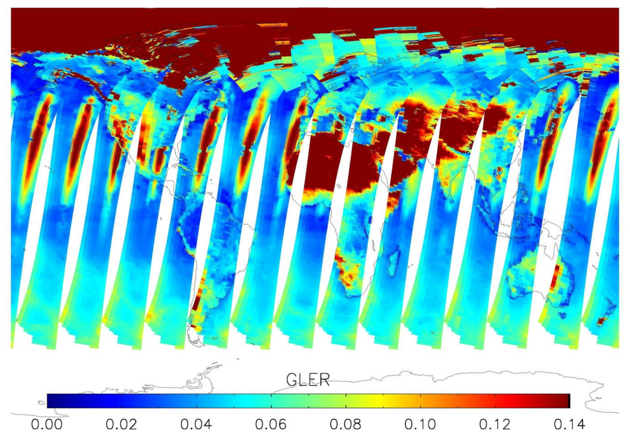


GOME-2A

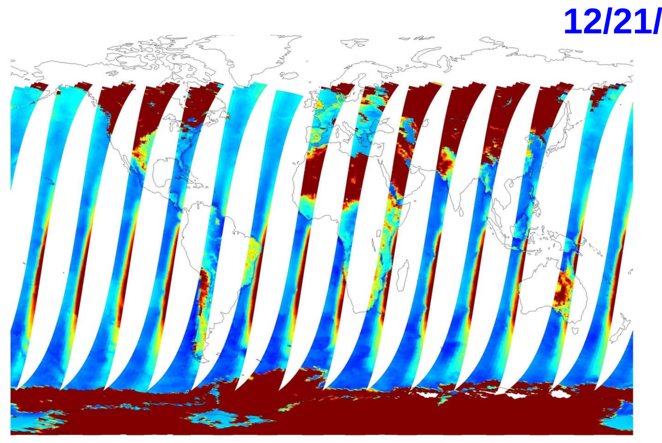
6/21/2015

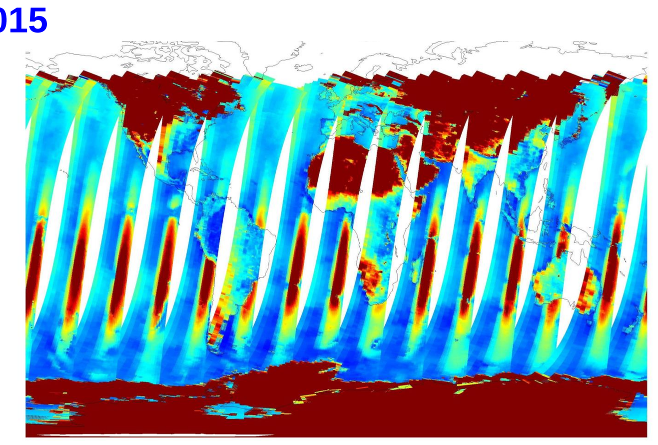
GOME-2B





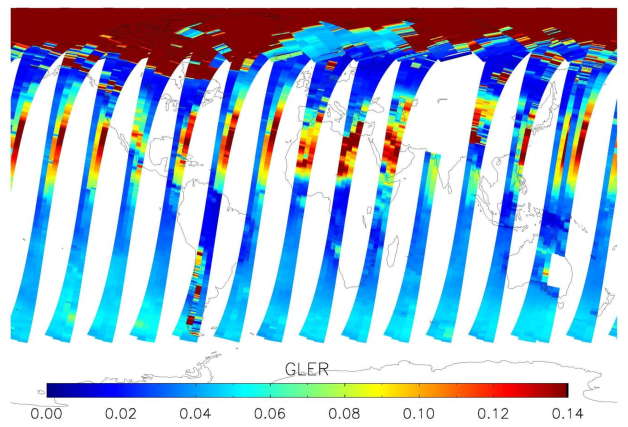
12/21/2015



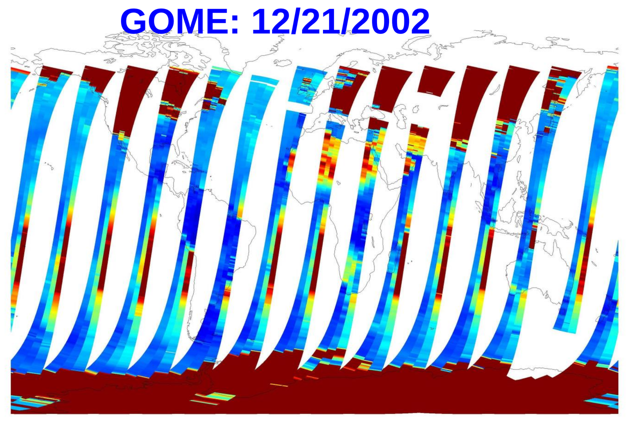


- Like GOME, GOME-2A has narrow swath, leaving big gaps between orbits.
- GOME-2B has wider swath and better coverage (esp. over ocean where the full sunglint is covered).
- GOME provides the earliest MINDS data record (1996-2003).

GOME: 6/21/2002

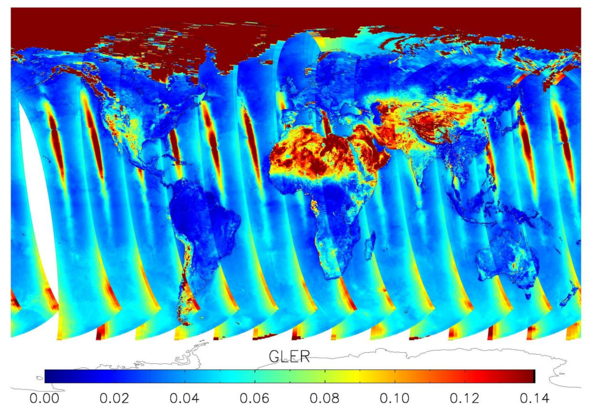


GOME: 12/21/2002

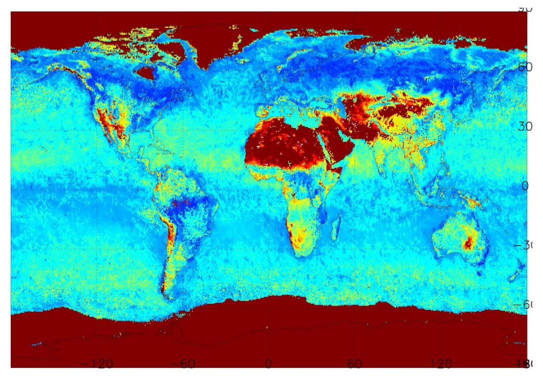


OMI GLER (466 nm) vs monthly LER climatology

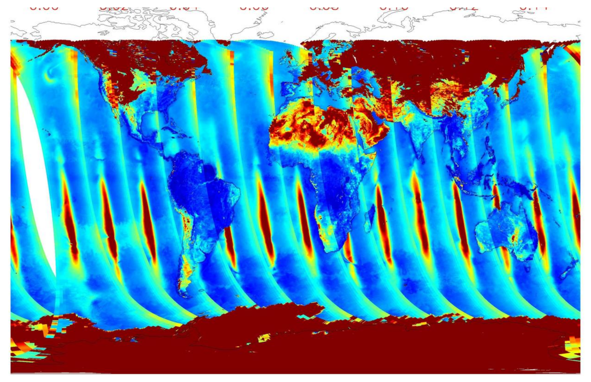
GLER: 6/21/2011



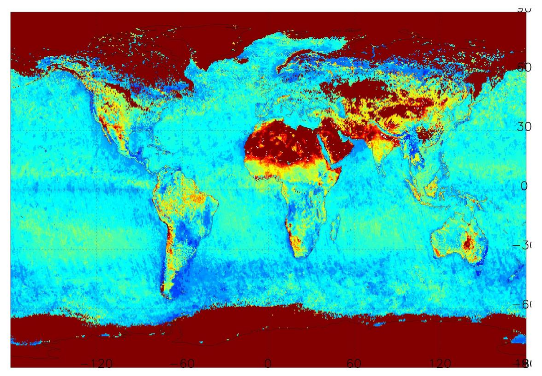
LER Climatology: June



GLER: 12/21/2011



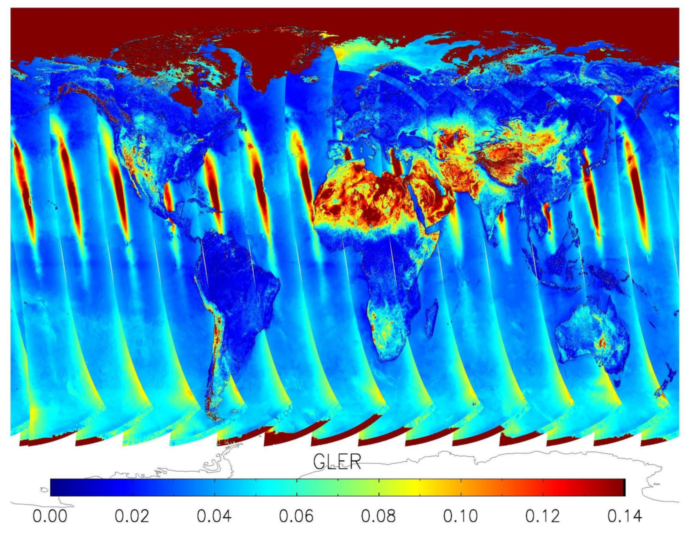
LER Climatology: Dec



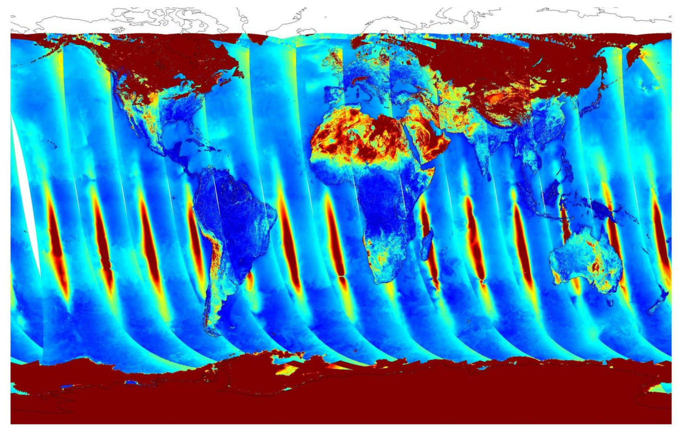
- GLER is generally lower than the climatology (Kleipool et al, 2008) due to less aerosol and cloud contamination that affects cloud and NO2 retrievals.
- The high spatial resolution of TROPOMI (3.5 km x 7.0 km) argues the need for a surface reflectivity database matching its footprint like GLER.

TROPOMI GLER

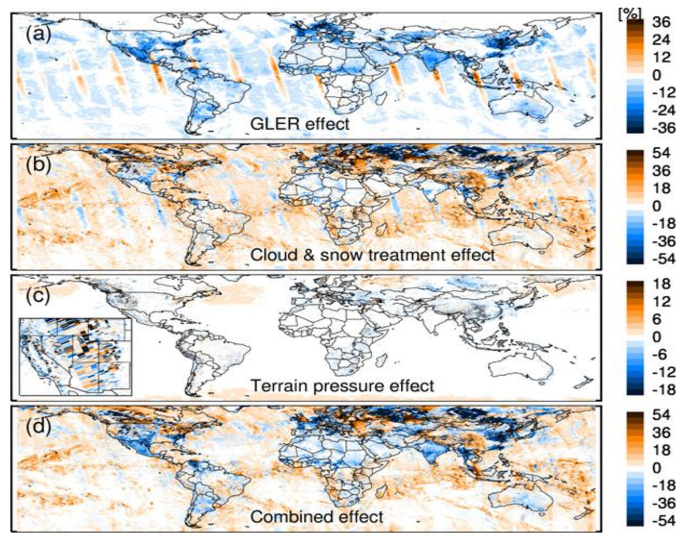
6/21/2019



12/21/2019



Sensitivities of tropospheric NO_2 AMF to different input parameters



- Shown on the left panel is the impact on tropospheric air mass factor (AMF) from changes in (a) surface reflectivity, (b) cloud and surface treatment, (c) terrain pressure, and (d) their combination on 20 March 2005.
- **The GLER impact (a) ranges from -50% to 25% for clear-sky scenes.**

Benefits of GLER approach

- captures solar and viewing angle dependencies.
- accounts for inter-annual surface changes.
- high spatial resolution accounts for inhomogeneous urban/suburban and coastal regions.
- requires no changes in operational cloud, aerosol and trace gas processors.
- **provides L2 global surface reflectivity data without gap at individual sensor's FoV.**

- GLER approach is currently used for satellite sensors considered in MINDS (OMI, TROPOMI, GOME-2A/B/C and GOME) and future sensor(s) as well (e.g., TEMPO).
- Data are available via https://measures.gesdisc.eosdis.nasa.gov/data/MINDS/TROPOMI_MINDS_NO2.1.1

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